California Air Resources Board

Quantification Methodology

California Department of Food and Agriculture
Alternative Manure Management Program

California Climate Investments

FINAL
March 10, 2022

Table of Contents

Section A. Introduction

California Climate Investments is a statewide initiative that puts billions of Cap-and-Trade dollars to work facilitating greenhouse gas (GHG) emission reductions; strengthening the economy; improving public health and the environment; and providing benefits to residents of disadvantaged communities, low-income communities, and low-income households, collectively referred to as "priority populations." Where applicable and to the extent feasible, California Climate Investments must maximize economic, environmental, and public health co-benefits to the State.

The California Air Resources Board (CARB) is responsible for providing guidance on estimating the GHG emission reductions and co-benefits from projects receiving monies from the Greenhouse Gas Reduction Fund (GGRF). This guidance includes quantification methodologies, co-benefit assessment methodologies, and benefits calculator tools. CARB develops these methodologies and tools based on the project types eligible for funding by each administering agency, as reflected in the program expenditure records available at: www.arb.ca.gov/cci-expenditurerecords.

For the California Department of Food and Agriculture (CDFA) Alternative Manure Management Program (AMMP), CARB staff developed this AMMP Quantification Methodology to provide guidance for estimating the GHG emission reductions and selected co-benefits of each proposed project type. This methodology uses calculations to estimate GHG emission reductions to be achieved through the implementation of new non-digester manure management practices or technologies that avoid the anaerobic decomposition of manure volatile solids and GHG emissions associated with the implementation of AMMP projects.

The AMMP Benefits Calculator Tool automates methods described in this document, provides a link to a step-by-step user guide with project examples, and outlines documentation requirements. Projects will report the total project GHG emission reductions and co-benefits estimated using the AMMP Benefits Calculator Tool as well as the total project GHG emission reductions per dollar of GGRF funds requested. The AMMP Benefits Calculator Tool is available for download at: http://www.arb.ca.gov/cci-resources.

Using many of the same inputs required to estimate GHG emission reductions, the AMMP Benefits Calculator Tool estimates the following co-benefits and key variables from AMMP projects: compost production (dry tons), compost application area (acres to be treated), fossil fuel reductions, fuel and energy cost savings, and reductions in reactive organic gases (ROG) (lbs), nitrogen oxides (NO_x) (lbs), particulate matter less than 2.5 microns in diameter ($PM_{2.5}$) (lbs), diesel particulate matter (diesel PM) (lbs). Key variables are project characteristics that contribute to a project's GHG emission reductions and signal an additional benefit (e.g., compost production and application). Additional co-benefits for which CARB assessment methodologies were not incorporated into the AMMP Benefits Calculator Tool may also be applicable to the project. Applicants should consult the AMMP guidelines, solicitation materials, and agreements to ensure they are meeting AMMP requirements. All CARB co-benefit assessment methodologies are available at: www.arb.ca.gov/cci-cobenefits.

Methodology Development

CARB and CDFA developed this Quantification Methodology consistent with the guiding principles of California Climate Investments, including ensuring transparency and accountability.[1] CARB and CDFA developed this AMMP Quantification Methodology to be used to estimate the outcomes of proposed projects, inform project selection, and track results of funded projects. The implementing principles ensure that the methodology would:

- Apply at the project-level;
- Provide uniform methods to be applied statewide, and be accessible by all applicants;
- Use existing and proven methods;
- Use project-level data, where available and appropriate; and
- Result in GHG emission reduction estimates that are conservative and supported by empirical literature.

CARB, in consultation with CDFA, assessed peer-reviewed literature and tools and consulted with experts, as needed, to determine methods appropriate for the AMMP project types. CARB also consulted with CDFA to determine project-level inputs available. The methods were developed to provide estimates that are as accurate as possible with data readily available at the project level.

The AMMP Quantification Methodology is adapted from CARB's 2014 Compliance Offset Protocol for Livestock Projects (Livestock Protocol). The Livestock Protocol was initially adopted by the Board on October 20, 2011 for the purpose of ensuring the complete, consistent, transparent, accurate, and conservative quantification of the net GHG benefit associated with a livestock digester offset project in order to generate CARB offset credits for use in the Cap-and-Trade Program. An updated version of the Livestock Protocol was adopted by the Board on November 14, 2014.

While the focus of the Livestock Protocol is the installation of a digester, the equations used to calculate current baseline scenario emissions are broadly applicable to livestock operations with anaerobic manure treatment and storage systems. It also contains equations for quantifying methane emissions from a variety of manure management practices and for quantifying fossil carbon dioxide emissions associated with manure management. These equations form the basis of this AMMP Quantification Methodology.

Several of the practices identified by CDFA as eligible for treating/storing scraped or separated manure solids do not have corresponding methane conversion factors (MCFs) in the Livestock Protocol. For these practices, this Quantification Methodology utilizes factors for

---

[1] California Air Resources Board. www.arb.ca.gov/cci-fundingguidelines

either a closely related practice based on the definitions in the Benefits Calculator Tool or utilizes the MCF for a practice expected to have a comparable MCF based on expert judgment. In particular, open solar drying uses the "dry lot" MCF; closed solar drying uses the "solid storage" MCF; and forced evaporation drying uses the "composting - static pile" MCF.

It should also be noted that while the Livestock Protocol is used to generate CARB offset credits based on measured data after implementation of a project, this Quantification Methodology is used to estimate the net GHG benefit of a project prior to project implementation in order to assist in awarding competitive GGRF grants. For this reason, this Quantification Methodology includes some simplifying assumptions in the quantification, monitoring and measurement of GHG emissions and emission reductions relative to the Livestock Protocol.

This Quantification Methodology also draws upon the extensive analysis conducted in a 2016 technical report of the UC Davis Biomass Collaborative that examined the economic costs and GHG mitigation potential of several alternative manure management practices.

CARB released the Draft AMMP Quantification Methodology and Draft AMMP Benefits Calculator Tool for public comment in November 2021. This Final AMMP Quantification Methodology and accompanying AMMP Benefits Calculator Tool have been updated to address public comments, where appropriate, and for consistency with updates to the AMMP Guidelines.

In addition, the University of California, Berkeley, in collaboration with CARB, developed assessment methodologies for a variety of co-benefits such as providing cost savings, lessening the impacts and effects of climate change, and strengthening community engagement. As they become available, co-benefit assessment methodologies are posted at: www.arb.ca.gov/cci-cobenefits.

Tools

The AMMP Benefits Calculator Tool relies on CARB-developed emission factors. CARB has established a single repository for emission factors used in CARB benefits calculator tools, referred to as the California Climate Investments Quantification Methodology Emission Factor Database (Database), available at: http://www.arb.ca.gov/cci-resources. The Database Documentation explains how emission factors used in CARB benefits calculator tools are developed and updated.

Applicants must use the AMMP Benefits Calculator Tool to estimate the GHG emission reductions and co-benefits of the proposed project. The AMMP Benefits Calculator Tool can be downloaded from: http://www.arb.ca.gov/cci-resources.

Updates

CARB staff periodically review each quantification methodology and benefits calculator tool to evaluate their effectiveness and update methodologies to make them more robust, user-friendly, and appropriate to the projects being quantified. CARB updated the AMMP Quantification Methodology from the previous version[2] to enhance the analysis and provide additional clarity. The changes include:

- Inclusion of vermifiltration and flocculant enhanced solid separation as new eligible practices;
- Modification of several inputs on "Project Data Inputs" tab to facilitate ease of use for applicants; and
- Updates to sloped screen solid and weeping wall separation factor.

[2] Quantification Methodology for the California Department of Food and Agriculture Alternative Manure Management Program released February 8, 2019.

Section B. Methods

The following section provides details on the methods supporting emission reductions in the AMMP Benefits Calculator Tool.

AMMP Project Types

AMMP supports several project types for which there are methods to quantify GHG emission reductions.[3] **To be eligible, an applicant's current manure management practices must include the anaerobic decomposition of manure volatile solids stored in a lagoon or other predominantly liquid anaerobic environment.** Methane (CH_4) is produced when volatile manure solids are stored in wet, anaerobic conditions; consequently, conditions that lead to methane production must currently exist at a dairy or livestock operation in order for methane emission reductions to be achieved through an AMMP project.

Each AMMP project requesting GGRF funding must include at least one of the following project components that reduce baseline methane emissions:

1. **Pasture-based management** including (i) conversion of a non-pasture dairy or livestock operation to pasture-based management; or (ii) increasing the amount of time livestock spend at pasture at an existing pasture operation.

Note: All pasture-based management projects must currently manage/store some manure in wet/anaerobic conditions and introduce new practices that reduce the quantity of manure managed under such conditions.

2. **Alternative manure treatment and storage** including:
    a) Installation of a **compost bedded pack barn** that composts manure in situ;
    b) Installation of **slatted floor pit storage manure collection** that must be cleaned out at least monthly.

Note: Pit storage cleaned out at a frequency less than twelve times per year is not eligible since this allows conditions to become anaerobic. Vermicomposting systems must be paired with a solid separation device.

3. **Solid separation** of manure solids prior to entry into a wet/anaerobic environment (e.g., lagoon, settling pond, settling basin) at a dairy or livestock operation *in conjunction with one of the following practices (a) through (i):*
    a) **Open solar drying** of manure (manure is dried in a paved or unpaved open confinement area without any significant vegetative cover where accumulating manure may be removed periodically);
    b) **Closed solar drying** (drying of manure in enclosed environment);

[3] https://www.cdfa.ca.gov/oefi/AMMP/

c) **Forced evaporation with natural-gas fueled dryers**;
d) **Daily spread** (manure is routinely removed from a confinement facility and is applied to cropland or pasture within 24 hours of excretion);
e) **Solid storage** (storage of manure, typically for a period of several months, in unconfined piles or stacks);
f) **Composting in vessel** (composting in an enclosed vessel, with forced aeration and continuous mixing) or **in aerated static pile** (composting in piles with forced aeration but no mixing);
g) **Composting in intensive windrows** (with regular – at least daily – turning for mixing and aeration) or **passive windrows** (with infrequent turning for mixing and aeration); or
h) **Solid separation with aerated vermifiltration system.**

Note: Either the installation of a new solid separation system at a dairy or livestock operation that does not currently employ solid separation, or the installation of a new solid separation system with significantly higher separation efficiency than the existing solid separation technology may be eligible.

4. **Conversion from a flush to scrape manure collection system** *in conjunction with one of the practices (a) through (h) in the list above.*

While solid separation or conversion from flush to dry scrape manure collection can be a critical component an AMMP project, these practices are not considered to be stand-alone in isolation from how manure is stored and treated. In order to calculate GHG emissions and emission reductions, it is also necessary to identify how the separated or collected manure volatile solids will be treated and/or stored (e.g., open solar drying, composting in vessel). Storage or further treatment will always take place with separated or collected solids, and applicants are required to identify what this will be. The storage or further treatment of the collected solids produces methane to varying degrees, as determined by the MCF for each practice. Applicants should use the definitions provided in the Benefits Calculator Tool to determine which practice most closely describes how they will manage separated or scraped manure volatile solids. If an applicant's treatment/storage practice does not exactly match the definition of a listed practice, they will identify the most-closely related practice.

Manure management projects that include the installation of a biogas control system (digester) are not eligible for AMMP. These projects may be eligible for funding under the Dairy Digester Research and Development Program (DDRDP), also administered by CDFA.

General Approach

Methods used in the AMMP Benefits Calculator Tool for estimating the GHG emission reductions and air pollutant emission co-benefits by activity type are provided in this section. The Database Documentation explains how emission factors used in CARB benefits calculator tools are developed and updated.

These methods account for the net GHG benefit of a proposed AMMP project based on a calculation of the avoided methane emissions from anaerobic manure decomposition after the adoption of alternative manure management practices. Methane production depends on the amount of manure produced, the fraction of volatile solids (VS) that decompose anaerobically (i.e., the biodegradable organic material in the manure), temperature, and the retention time of manure during treatment and storage. This methodology combines project-specific data with default factors to establish both a baseline scenario and a project scenario.

Net GHG emission reductions are calculated by subtracting estimated post-project GHG emissions from the baseline scenario emissions. The project boundary includes both methane emissions from manure as well as fossil fuel based carbon dioxide emissions associated with manure management activities.

In general, the GHG emission reductions are estimated in the AMMP Benefits Calculator Tool using the approaches in Table 1. The AMMP Benefits Calculator Tool also estimates air pollutant emission co-benefits and key variables using many of the same inputs used to estimate GHG emission reductions.

Table 1. General Approach to Quantification by Project Type

Adoption of Alternative Manure Management Practices
Emission Reductions = (Baseline CH_4 and CO_2 emissions) – (Project CH_4 and CO_2 emissions)

A. Emission Reductions from project type

Methods used in the AMMP Benefits Calculator Tool for estimating the net GHG emission reductions by activity type are provided in this section. The GHG emission reductions from the project are quantified within the AMMP Calculator Tool using the equations below.

The GHG emission reductions from AMMP projects is calculated using Equation 9 as the difference between the baseline and project scenarios.

B. Calculation of Annual Baseline Methane Emissions

Baseline scenario methane emissions (BE_{CH4}) represent the emissions within the Project Boundary that would have occurred without adoption of alternative manure management practices. Applicants should use data from the previous 12 months of dairy operation in addition to the appropriate default factors. Baseline emissions must be calculated according to the manure management system in place prior to the AMMP project.

The procedure to determine the project baseline methane emissions uses Equations 1, 2 and 3, with Equations 2 and 3 as inputs to Equation 1. Equation 2 calculates CH_4 emissions from anaerobic manure storage/treatment systems (e.g., anaerobic lagoons, storage ponds, settling ponds, settling basins, etc.) based on project-specific mass of volatile solids degraded by the anaerobic storage/treatment system and available for methane conversion. The equation incorporates the effects of temperature and accounts for the retention of volatile solids. Equation 3 applies to predominantly non-anaerobic storage/treatment systems and is used to calculate emissions from separated solids and other volatile solids not sent to a wet/anaerobic environment. Both Equations 2 and 3 reflect basic biological principles of methane production from available volatile solids, determine methane generation for each livestock category, and account for the extent to which the waste management system manages each category's manure. The calculation procedure uses a combination of project-specific variables and default factors:

Population – P_L
The procedure for establishing population values requires the applicant to differentiate between livestock categories ('L') such as lactating dairy cows, dry cows (non-milking dairy cows), heifers, etc., to account for differences in methane generation across livestock categories. The population of each livestock category is monitored on a monthly basis and averaged for an annual total population for the previous 12 months.

Volatile Solids – VS_L
This value represents the daily organic material in the manure for each livestock category and consists of both biodegradable and non-biodegradable fractions. The VS content of manure is a combination of excreted fecal material (the fraction of a livestock category's diet consumed and not digested) and urinary excretions, expressed in a dry matter weight basis (kg/animal).

Average Weight – $Mass_L$
This value is the annual average live weight of the animals, per livestock category. Typical Average Mass (TAM) values are used.

Maximum Methane Production – $B_{0,L}$
This value represents the maximum methane-producing capacity of the manure, differentiated by livestock category ('L') and diet.

Manure Management System – MS
The MS value apportions volatile solids from each livestock category to an appropriate manure management system component ('S'). The MS value accounts for the operation's multiple types of manure management systems and is expressed as a percent (%), relative to the total amount of volatile solids produced by the livestock category. As waste production is normalized for each livestock category, the percentage should be calculated as percent of population for each livestock category. For example, a dairy operation might flush 30% of its milking cows' waste to an anaerobic lagoon while 70% is deposited in a corral. In this example, an MS value of 30% would be assigned to Equation 2 and 70% to Equation 3.

The MS value also accounts for the fraction of volatile solids separated through a solid separation technology. Default values are used to calculate an MS value for separated solids.

Methane Conversion Factor – MCF
Each manure management system component has a volatile solids-to-methane conversion efficiency, which represents the degree to which maximum methane production (B0) can be achieved. Default MCF values for non-anaerobic manure storage/treatment are used for Equation 3.

Equation 1: Baseline Methane Emissions

$$BE_{CH4} = BE_{CH4\ AS} + BE_{CH4\ non-AS}$$

Where,			Units
BE_{CH4}	=	Total annual project baseline methane emissions	$MTCO_2e/yr$
$BE_{CH4,AS}$	=	Total annual project baseline methane emissions from anaerobic storage/treatment systems	$MTCO_2e/yr$
$BE_{CH4,non-AS}$	=	Total annual project baseline methane emissions from predominantly non-anaerobic storage/treatment systems	$MTCO_2e/yr$

Equation 2: Baseline Methane Emissions from Anaerobic Storage / Treatment

$$BE_{CH_4,AS} = \sum_{l,i} (VS_{\deg\ AS,l,i} \times B_{0,l}) \times 0.68 \times 0.001 \times 25$$

Where,			Units
$BE_{CH4,AS}$	=	Total annual project baseline methane emissions from anaerobic manure storage/treatment systems	$MTCO_2e/yr$
$VS_{degAS,L,i}$	=	Monthly volatile solids degraded in anaerobic manure storage/treatment system 'AS' from livestock category 'L' in month 'i'	kg dry matter
$B_{0,L}$	=	Maximum methane producing capacity of manure for livestock category 'L'	m^3-CH_4/ kg of VS
0.68	=	Density of methane (1 atm, 60°F)	kg/m^3
0.001	=	Conversion factor from kg to metric tons	
25	=	Global warming potential of methane[iii]	

With:

$$VS_{\deg,AS,L,i} = f_i \times VS_{avail,AS,L,i}$$

Where,			Units
$VS_{deg,AS,L,i}$	=	Volatile solids degraded by anaerobic manure storage/ treatment system 'AS' by livestock category 'L' in month "i"	kg dry matter
$VS_{avail,AS,L,i}$	=	Monthly volatile solids available for degradation from anaerobic manure storage/treatment system 'AS' by livestock category 'L'	kg dry matter
f_i	=	The van't Hoff-Arrhenius factor = "the proportion of volatile solids that are biologically available for conversion to methane based on the monthly average temperature of the system"	

With:

$$f_i = MIN\left(\exp\left[\frac{E(T_2 - T_1)}{RT_1T_2}\right], 0.95\right)$$

Where,			Units
f	=	The van't Hoff-Arrhenius factor for month "i"	
E	=	Activation energy constant (15,175)	cal/mol
T_1	=	303.16	Kelvin
T_2	=	Monthly average ambient temperature (K = °C + 273). If $T_2 < 5$ °C then f = 0.104[iv]	Kelvin
R	=	Ideal gas constant (1.987)	cal/K-mol

Equation 2: Baseline Methane Emissions from Anaerobic Storage / Treatment Systems (continued)

And:

$$VS_{avail,AS,L,i} = \left(VS_L \times P_L \times MS_{AS,L} \times dpm_i \times 0.8\right) + \left(VS_{avail,AS,L,i-1} - VS_{\deg,AS,L,i-1}\right)$$

Where,

			Units
$VS_{avail,AS,L,i}$	=	Volatile solids available for degradation in anaerobic storage/treatment system 'AS' by livestock category 'L' in month 'i'	kg dry matter
VS_L	=	Volatile solids produced by livestock category 'L' on a dry matter basis.	kg/ animal/ day
P_L	=	Annual average population of livestock category 'L' (based on monthly population data)	
$MS_{AS,L}$	=	Fraction of volatile solids sent to (managed in) anaerobic manure storage/treatment system 'AS' from livestock category 'L'	%
dpm_i		Days per month 'i'	days
0.8	=	System calibration factor	
$VS_{avail,AS,L,i-1}$	=	Previous month's volatile solids available for degradation in anaerobic system 'AS'	kg
$VS_{deg,AS,L,i-1}$	=	Previous month's volatile solids degraded by anaerobic system 'AS'	kg

With:

$$VS_L = VS_{table} \times \frac{Mass_L}{1000}$$

Where,

VS_L	=	Volatile solid excretion on a dry matter weight basis	kg/ animal/ day
VS_{table}	=	Volatile solid excretion	kg/ day/ 1000kg
$Mass_L$	=	Average live weight for livestock category 'L'	kg

Equation 3: Baseline Methane for Non-Anaerobic Storage/Treatment Systems

$$BE_{CH_4,non-AS} = \sum_{s,l} (P_l \times MS_{non-AS,s,l} \times VS_l \times 365.25 \times MCF_s \times B_{0,l}) \times 0.68 \times 0.001 \times 25$$

Where,

			Units
$BE_{CH4,non-AS}$	=	Total annual baseline methane emissions from predominantly non-anaerobic storage/treatment systems	$MTCO_2e/yr$
P_L	=	Annual average population of livestock category 'L' (based on monthly population data)	
$MS_{non-AS,s,L}$	=	Fraction of volatile solids from livestock category 'L' managed in non-anaerobic storage/treatment system 's'	%
VS_L	=	Volatile solids produced by livestock category 'L' on a dry matter basis	kg/ animal/ day
365.25	=	Days in a year	days
MCF_s	=	Methane conversion factor for non-anaerobic storage/treatment system 's'	%
$B_{0,L}$	=	Maximum methane producing capacity for manure for livestock category 'L'	m^3-CH_4/kg of VS dry matter
0.68	=	Density of methane (1 atm, 60°F)	kg/m^3
0.001	=	Conversion factor from kg to metric tons	
25	=	Global warming potential factor of methane	
S	=	Manure treatment/storage system	

C. Estimation of Project Methane Emissions

Even after adoption of alternative manure management practices, some methane will still be emitted to the atmosphere. If any volatile solids are still expected to be sent to the anaerobic treatment/storage system (e.g., lagoon, settling pond, settling basin) after adoption of alternative practices, these emissions are estimated using Equation 4.

Applicants must also calculate CH_4 emissions from any volatile solids sent to other waste management and storage systems after the adoption of alternative practices (including but not limited to separated solids) using Equation 5.

Total project methane emissions after adoption of alternative manure management practices are summed in Equation 6.

Equation 4: Estimated Project Methane Emissions from Anaerobic Storage / Treatment

$$PE_{CH4,AS} = \sum_{l,i} (VS_{\deg AS,l,i} \times B_{0,l}) \times 0.68 \times 0.001 \times 25$$

Where,			<u>Units</u>
$PE_{CH4,AS}$	=	Total annual project methane emissions from anaerobic manure storage/treatment systems	$MTCO_2e/yr$
$VS_{degAS,L,i}$	=	Monthly volatile solids degraded in anaerobic manure storage/treatment system 'AS' from livestock category 'L' in month 'i'	kg dry matter
$B_{0,L}$	=	Maximum methane producing capacity of manure for livestock category 'L'	m^3 CH_4/kg of VS
0.68	=	Density of methane (1 atm, 60°F)	kg/m^3
0.001	=	Unit conversion factor	kg/MT
25	=	Global warming potential of methane	$MTCO_2e/MTCH_4$

With:

$$VS_{\deg,AS,L,i} = f_i \times VS_{avail,AS,L,i}$$

Where,			<u>Units</u>
$VS_{deg,AS,L,i}$	=	Volatile solids degraded by anaerobic manure storage/ treatment system 'AS' by livestock category 'L' in month "i"	kg dry matter
f_i	=	The van't Hoff-Arrhenius factor = "the proportion of volatile solids that are biologically available for conversion to methane based on the monthly average temperature of the system"	unitless
$VS_{avail,AS,L,i}$	=	Monthly volatile solids available for degradation from anaerobic manure storage/treatment system 'AS' by livestock category 'L'	kg dry matter

With:

$$f_i = MIN\left(\exp\left[\frac{E(T_2 - T_1)}{RT_1T_2}\right], 0.95\right)$$

Where,			<u>Units</u>
f	=	The van't Hoff-Arrhenius factor for month "i"	unitless
E	=	Activation energy constant (15,175)	cal/mol
T_1	=	303.16	Kelvin
T_2	=	Monthly average ambient temperature (K = °C + 273). If T_2 < 5 °C then f = 0.104	Kelvin
R	=	Ideal gas constant (1.987)	cal/K-mol

Equation 4: Estimated Project Methane Emissions from Anaerobic Storage / Treatment Systems (continued)

And:

$$VS_{avail,AS,L,i} = \left(VS_L \times P_L \times MS_{AS,L} \times dpm_i \times 0.8\right) + \left(VS_{avail,AS,L,i-1} - VS_{deg,AS,L,i-1}\right)$$

Where,

			Units
$VS_{avail,AS,L,i}$	=	Volatile solids available for degradation in anaerobic storage/treatment system 'AS' by livestock category 'L' in month 'i'	kg dry matter
VS_L	=	Volatile solids produced by livestock category 'L' on a dry matter basis	kg/ animal/ day
P_L	=	Annual average population of livestock category 'L' (based on monthly population data)	animals
$MS_{AS,L}$	=	Fraction of volatile solids sent to (managed in) anaerobic manure storage/treatment system 'AS' from livestock category 'L'	%
dpm_i		Days per month 'i'	days
0.8	=	System calibration factor	unitless
$VS_{avail,AS,L,i-1}$	=	Previous month's volatile solids available for degradation in anaerobic system 'AS'	kg
$VS_{deg,AS,L,i-1}$	=	Previous month's volatile solids degraded by anaerobic system 'AS'	kg

With:

$$VS_L = VS_{table} \times \frac{Mass_L}{1000}$$

Where,

VS_L	=	Volatile solid excretion on a dry matter weight basis	kg/ animal/ day
VS_{table}	=	Volatile solid excretion	kg/ day/ 1000kg
$Mass_L$	=	Average live weight for livestock category 'L'	kg
1000	=	Unit conversion factor	kg/MT

Equation 5: Estimated Project Methane for Non-Anaerobic Storage/Treatment Systems

$$PE_{CH_4,non-BCS} = \sum_{s,l} (P_l \times MS_{non-BCS,s,l} \times VS_l \times 365 \times MCF_s \times B_{0,l}) \times 0.68 \times 0.001 \times 25$$

Where,			Units
$PE_{CH4,non-BCS}$	=	Total annual methane emissions from other waste storage/treatment systems after installation of BCS	$MTCO_2e/yr$
P_L	=	Annual average population of livestock category 'L' (based on monthly population data)	animal
$MS_{non-BCS,s,L}$	=	Percent of volatile solids from livestock category 'L' managed in non-BCS storage/treatment system 's'	%
VS_L	=	Volatile solids produced by livestock category 'L' on a dry matter basis	kg/ animal/ day
365.25	=	Days in a year	days
MCF_s	=	Methane conversion factor for non-anaerobic storage/treatment system 's'	%
$B_{0,L}$	=	Maximum methane producing capacity for manure for livestock category 'L'	m^3 CH_4/kg of VS dry matter
0.68	=	Density of methane (1 atm, 60°F)	kg/m^3
0.001	=	Conversion factor from kg to metric tons	
25	=	Global warming potential factor of methane	$MTCO_2e$/ $MTCH_4$

Equation 6: Total Project Methane Emissions

$$PE_{CH4} = PE_{CH4,AS} + PE_{CH4,non-AS}$$

Where,			Units
PE_{CH4}	=	Estimated methane emissions after adoption of alternative manure management practices	$MTCO_2e/yr$
$PE_{CH4,AS}$	=	Estimated annual methane emissions from anaerobic storage/treatment systems	$MTCO_2e/yr$
$PE_{CH4,non-AS}$	=	Estimated annual methane emissions from other waste storage/treatment systems	$MTCO_2e/yr$

D. Calculation of Anthropogenic Carbon Dioxide Emissions Associated with Manure Management Practices

Carbon dioxide emission sources associated with manure management activities include but are not limited to: electricity use by pumps and equipment, fossil fuel generators used to destroy biogas or power pumping systems or milking parlor equipment; flares; tractors that operate in barns or freestalls; heaters used to dry manure; on-site manure hauling trucks; or vehicles that transport manure off-site. For the purposes of calculating baseline CO_2 emissions, applicants should use data from the previous 12 months of dairy operation in addition to the appropriate default factors. Use Equation 7 to calculate baseline carbon dioxide emissions.

Stationary and Mobile Source Emissions: Carbon dioxide emissions associated with manure management activities may decrease, increase or remain unchanged as a result of adopting alternative manure management practices. Applicants should pay particular attention to any changes in manure collection or transport practices, such as if manure is trucked to a central location or compost is trucked offsite, and if there are any new fossil fuel combustion sources, such as diesel-powered scrapers or tractors.

Applicants must include a list of all relevant CO_2 emission sources by fuel type. Baseline emissions are calculated based on previous 12-months fuel consumption by fuel type. Project emissions are estimated by the applicant. Applicants must include an explanation of how adoption of alternative manure management practices will affect fuel consumption by these sources, and estimate emissions for any new sources.

Indirect Electricity Emissions: Projects should include indirect emissions associated with electricity use in the baseline using data from the previous 12 months of dairy operation. Applicants must also estimate annual electricity consumption after adoption of alternative manure management practices.

Equation 7: Baseline Carbon Dioxide Emissions from Mobile and Stationary Support Equipment, and Electricity Consumption

$$BE_{CO_2} = \left(\sum_c QE_c \times EF_{CO_2,e} \right) + \left[\left(\sum_c QF_c \times EF_{CO_2,f} \right) \times 0.001 \right]$$

Where,			Units
BE_{CO2}	=	Anthropogenic carbon dioxide emissions from electricity consumption, and mobile and stationary combustion sources	$MTCO_2$/yr
QE_c	=	Quantity of electricity consumed for each emissions source "c"	MWh/yr
$EF_{CO2,e}$	=	CO_2 emission factor e for electricity used[v]	$MTCO_2$/MWh
QF_c	=	Quantity of fuel consumed for each mobile and stationary CO_2 emission source 'c'	MMBtu/yr or gallon/yr
$EF_{CO2,f}$	=	Fuel-specific emission factor f	$kgCO_2$/MMBtu or $kgCO_2$/gal
0.001	=	Conversion factor from kg to metric tons	MT/kg

Equation 8 is used to calculate project CO_2 emissions. Any source included in the baseline must be included in the project, unless CO_2 emissions from that source are reasonably expected to be zero after adoption of alternative manure management practices. When applying Equation 8, individual sources may be aggregated by total electricity consumption and by fuel type.

Equation 8: Project Carbon Dioxide Emissions from Mobile and Stationary Equipment, and Electricity Consumption

$$PE_{CO_2} = \left(\sum_c QE_c \times EF_{CO_2,e}\right) + \left[\left(\sum_c QF_c \times EF_{CO_2,f}\right) \times 0.001\right]$$

Where,			Units
PE_{CO2}	=	Anthropogenic carbon dioxide emissions from electricity consumption and mobile and stationary combustion sources	$MTCO_2$/yr
QE_c	=	Quantity of electricity consumed for each emissions source "c"	MWh/yr
$EF_{CO2,e}$	=	CO_2 emission factor e for electricity used	$MTCO_2$/ MWh
QF_c	=	Quantity of fuel consumed for each mobile and CO_2 stationary emission source 'c'	MMBtu/yr or gallon/yr
$EF_{CO2,f}$	=	Fuel-specific emission factor f	kg CO_2/ MMBtu or kg CO_2/gal
0.001	=	Conversion factor from kg to metric tons	MT/kg

E. Calculation of the GHG emission reduction attributable to the project

GHG emission reductions from an AMMP project are quantified by summing the baseline methane and anthropogenic carbon dioxide emissions, and subtracting from this any remaining project emissions using Equation 9. Emission reductions are aggregated over a 5 year period, the minimum project life-time.

Equation 9: Project GHG Emission Reductions from Adoption of Alternative Manure Management Practices

$$ER = (BE_{CH_4} + BE_{CO_2} - PE_{CH_4} - PE_{CO_2}) \times 5$$

Where,

			Units
ER	=	Total estimated project GHG emission reductions over 5 years	$MTCO_2e$
BE_{CH4}	=	Annual baseline methane emissions	$MTCO_2e$/yr
BE_{CO2}	=	Baseline carbon dioxide emissions associated with manure management from stationary and mobile sources	$MTCO_2e$/yr
PE_{CH4}	=	Estimated methane emissions after adoption of alternative manure management practices	$MTCO_2e$/yr
PE_{CO2}	=	Estimated carbon dioxide emissions associated with manure management from stationary and mobile sources after adoption of alternative manure management practices	$MTCO_2e$/yr
5	=	Minimum project lifetime	years

F. Calculation of Other Reported Metrics

In addition to a calculation of the total GHG emission reductions over 5 years, the AMMP Calculator Tool also computes the following metrics:

- GHG reduction per $ GGRF grant money invested over 5 years;
- For dairy applicants only, the GHG reduction per unit energy-corrected milk produced over 5 years; and
- GHG reduction per animal within the project boundary over 5 years.

The calculation of GHG reduction per unit energy-corrected milk uses the energy corrected milk production calculated using Equation 10:

Equation 10: Energy-Corrected Milk (ECM)

$$ECM = \frac{(\text{Fat} \times 41.65) + (\text{Protein} \times 24.13) + (\text{Lactose} \times 21.60) - 11.72}{1000} \times \frac{2.204 \times \text{Milk}}{0.721}$$

Where,			Units
ECM	=	Energy-Corrected Milk	kg/cow/d
Fat	=	Milk fat %	%
41.65	=	Energetic value for fat	
Protein	=	Milk true protein %	%
24.13	=	Energetic value for protein	
Lactose	=	Milk lactose %	%
21.60	=	Energetic value for lactose	
11.72	=	Correction Factor	
2.204	=	Weight conversion	lbs/kg
Milk	=	Average milk produced	kg/cow/d
0.721	=	Energy value of 1 kg of standard milk (standard milk is defined for this program as 3.75% fat, 3.0% true protein and 4.9% lactose).	Mcal/kg

Diary project applicants must use dairy-specific values for fat, true protein, and lactose characteristics when available. If unavailable, the default values for standard milk may be used. The ECM is used to estimate energy-corrected milk production in metric tons over 5 years. Dividing the net GHG emission reduction over 5 years by this value yields the GHG reduction per unit energy-corrected milk produced metric.

G. Calculation of Air Pollutant Co-benefits

The criteria and toxic air pollutant co-benefits are estimated as the difference between emissions in the baseline and project scenarios. Emissions are calculated based on electricity use and diesel fuel consumption, multiplied by the appropriate emission factor. Emission reductions related to changes in diesel fuel consumption are considered "local," as they occur at or near the project site, while emission reductions related to changes in electricity use are considered "remote," as they are distributed across the State. Note that positive values correspond to emission reductions, while negative values correspond to increases.

Equation 11: Criteria and Toxic Air Pollutant Reductions (local)

$$CT_{local,i} = -(QF_{ps} - QF_{bs}) \times EF_i \times 5$$

Where,

			Units
$CT_{local,i}$	=	Local reductions in criteria air pollutant or toxic air contaminant "i" (where i = NOx, ROG, PM 2.5, and diesel PM)	lbs
QF_{ps}	=	Quantity of diesel fuel combusted annually in the project scenario	gallons
QF_{bs}	=	Quantity of diesel fuel combusted annually in the baseline scenario	gallons
EF_i	=	Aggregate non-specified agricultural sector emission factor for criteria air pollutant or toxic air contaminant "i"	lbs/gallon
5	=	Minimum project lifetime	years

Equation 12: Criteria and Toxic Air Pollutant Reductions (remote)

$$CT_{remote,i} = -(QE_{ps} - QE_{bs}) \times EF_i \times 5$$

Where,

			Units
$CT_{remote,i}$	=	Remote reductions in criteria air pollutant or toxic air contaminant "i" (where i = NOx, ROG, PM 2.5, and diesel PM)	lbs
QE_{ps}	=	Quantity of electricity consumed annually in the project scenario	MWh
QE_{bs}	=	Quantity of electricity consumed annually in the baseline scenario	MWh
EF_i	=	Grid emission factor for criteria air pollutant or toxic air contaminant "i"	lbs/MWh
5	=	Minimum project lifetime	years

Section C. References

The following references were used in the development of this Quantification Methodology and the AMMP Benefits Calculator Tool.

California Air Resources Board. (2014). *Compliance Offset Protocol for Livestock Projects: Capturing and Destroying Methane from Manure Management Systems.* https://www.arb.ca.gov/cc/capandtrade/offsets/offsets.htm.

California Air Resources Board. (2011). *Compliance Offset Protocol for Livestock Projects: Capturing and Destroying Methane from Manure Management Systems.* https://www.arb.ca.gov/cc/capandtrade/offsets/offsets.htm.

California Air Resources Board (2017). California Climate Investments Quantification Methodology Emission Factor Database. Available at: www.arb.ca.gov/cci-resources.

California Air Resources Board (2017). Quantification Methodology for the California Department of Food and Agriculture Alternative Manure Management Program; Greenhouse Gas Reduction Fund; Fiscal Years 2016-17 & 2017-18. March 27, 2018. Available at: https://www.arb.ca.gov/cc/capandtrade/auctionproceeds/quantification-archive.htm.

California Climate Data Archive: http://www.calclim.dri.edu/pages/stationmap.html.

UC Davis California Biomass Collaborative. (2016). *Evaluation of Dairy Manure Management Practices for Greenhouse Gas Emissions Mitigation in California: FINAL TECHNICAL REPORT to the State of California Air Resources Board*. Stephen Kaffka, et al. http://biomass.ucdavis.edu/wp-content/uploads/2016/06/ARB-Report-Final-Draft-Transmittal-Feb-26-2016.pdf.

UC Davis California Biomass Collaborative. (2020) *Research and Technical Analysis to Support and Improve the Alternative Manure Management Program Quantification Methodology.* Stephen Kaffka, Robert B. Williams, Hamed Elmashad. https://ww2.arb.ca.gov/sites/default/files/classic/cc/capandtrade/auctionproceeds/ucd_ammp_qm_analysis_final_april2020.pdf